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CYCLIC GROWTH IN ATLANTIC REGION CONTINENTAL CRUST; A.M. Goodwin, Department of Geology, University of Toronto, Toronto, Canada M5S 1A1

The four continents of the Atlantic region -- Europe, North America with Greenland, South America, and Africa with Arabia and Madagascar -- contain large Precambrain platforms which, together with adjoining Phanerozoic mobile belts, give evidence of cyclic continental growth, involving regular ca. 400 Ma-long cycles.

Precambrain continental platforms comprise both exposed shields and buried basement. Recently compiled maps serve to provide the areal proportions by eon and era of exposed and buried rocks in the Precambrian platforms of the Atlantic region (Table 1). Because the basis of classification is radiometric dating, rocks assigned to an era include both newly formed rocks and reworked (metamorphosed) older crust. Thus areal proportions by era reflect accumulated orogenic history, the younger eras gaining at the expense of the older. In fact significant survival of older crust e.g. Archean (14%) and Early Proterozoic (22%), requires enduring cratonization during continental growth, attributable to deep sub-shield tectospheric roots (1).

The proportions by era (and eon) (A,B,C,D in Table 1) of exposed Precambrian crust only in the combined continents of the Atlantic region are roughly equal with A (33%) being the highest and B (21%) the lowest. Considered by continent, divisions C and D are significantly high in North America, B in South America, and A in Africa; A and B are unusually low respectively in North America and Africa. However, considering entire platforms (exposed & buried Precambrian crust) the youngest era (A) predominates as expressed in D:C:B:A = 1 : 1.6 : 1.3 : 3.3. Geologically this expresses 1) widespread Pan-African influence in Africa and South America, and 2) the presence of large Late Proterozoic-Phanerozoic-filled basins in Europe (Moscow Syneclise) and Africa (Taoudeni and Congo).

Considering relative sizes by continent of Precambrian platforms and adjoining Phanerozoic mobile belts (Table 2), the European platform is the smallest and the African platform the largest (x3.7). Phanerozoic belts of Europe (Hercynides-Caledonides-Alpides) are the largest, and of Africa (Cape-Mauritanides-Atlas) the smallest. In all continents except Europe the Precambrian platform is substantially larger than the adjoining Phanerozoic mobile belts. The combined continental crust by continent is, in increasing order of size, South America, Europe, Africa, North America. Thus each continent is an aggregate of partly covered interior Precambrian platform of designated composition and peripheral Phanerozoic mobile belts.

Gastil (2) established that abundant global igneous and metamorphic dates, corresponding to periods of orogeny, are about 210 Ma in length, and alternate with like periods of mineral date scarcity (tectonic quiessence) for a mean 417 Ma-long cyclic distribution pattern extending back to 2600 Ma. This pattern corresponds to long cycles in Earth's orogenic history, the peaks in the number of radiometric ages coresponding to terminal events of the major crustal processes. Post-1960 dating, extending back to 3.8 Ga, supports the validity of Gastil's main peaks of mineral dates marking global orogenies and accelerated crustal growth. The main culminations occur approximately at 2.6, 1.8, 1.0 and 0.6 Ga, which respectivly demarcate Archean eon (D), and Early-(C), Mid-(B) , and Late-Proterozoic (A) eras; others are dated at 3.5, 3.0 and 2.2 Ga. In close accord, Cahen et al. (3) select the following dates as chronological milestones in the evolution of Africa, the continent with the largest Precambrian platform (Table 2), each date marking the approximate age of comparatively widespread events: 3.5, 2.9, 2.5, 2.1, 1.75, 1.1 and 0.57 Ga.

Culminations of the same crustal processes are also reflected in the post-Archean paleomagnetic record by "hairpin" turns which mark sudden reversals in the sense of polar motion of continental plates (4). Worsley et al. (5) summarize a "non-random" crustal model to account for long-term tectonic cyclicity. Plate motion is attributed, accordingly, to a thermal instability mechanism (6) resulting from the repeated assembly of supercontinents (Pangea) that never completely disperse. A pattern of plate tectonic cycles, each cycle of about 400 Ma duration, is recognized back to 2000 Ma. The popular "random" plate motion model (7), however, advocates that Mesozoic Pangea represents assemblage of continental fragments dispersed from a still-earlier supercontinent centred on the Pacific Ocean, and now marked by the central Pacific residual geoid high. Le Pichon and Huchon (8) in turn, interpret evidence pertaining to the geoid and supercontinent in terms of a weak coupling of a separate steady-state lower mantle, which is responsible for the present geoid, to upper mantle convection leading to hemispheric continental configuration (Pangea) which ends when excessive heating of the upper mantle due to the insulating continental cap leads to continental dispersal, the complete cycle from one supercontinent to the next being in the order of 400 Ma. Thus whatever model is used, the evidence points to regular cyclicity in the evolution of continental crust. Specifically, taken together with the ongoing plate cycle (since 0.2 Ga), the data on Atlantic region crust provide for a regular cyclic pattern of about 400 Ma duration, a pattern involving 8 cycles back to 3.0 Ga.

The Atlantic region of the collective Europe-Americas-African plates has experienced repeated horizontal crustal oscillations. Including the modern Atlantic opening, at least 3 (to 1.0 Ga) and possibly 4 (to 1.4 Ga) coherent Wilson cycles have been tracked, each involving early divergence with supracrustal accumulation followed by convergence and orogeny over about 400 Ma. For the most part these particular cycles are readily interpreted in terms of modern plate tectonic processes involving ocean floor consumption with active and passive continental margins. However, whereas certain intercontinental Pan-African belts, e.g. Pharusides, do likewise carry Wilson cycle signature, others, e.g. Damara-Katanga, Ribeira, Paraguay, are apparently ensialic in origin and suggest a different tectonic origin. Mid-Proterozoic (B) crust (cycles 4,5) is characterized by widespread anorogenic magmatism, aborted rifts and aulacogens together with major mobile belts (Grenville, Rondonian), some apparently ensialic (Kibarides, Espinhaco). Paleomagnetic data suggests a single stable supercontinent (9). The nature of the operating plate tectonic processes is highly controversial and uncertain. Early Proterozoic (C) crust (cycles 6,7) features numerous, commonly asymmetric fold belts which appear, more often than not, to be superposed on an ensialic basement. Some belts, however, e.g. Coronation, closely resemble Phanerozoic equivalents. Still others, e.g. Birrimian, contain Archean-type greenstone belts. Most belts are severely deformed as a result of low-angle foreland transport. This tectonic mobility is frequently followed by intensive and repeated granitoid intrusion, commonly with ring-structures, generally high-level, often alkaline, and linked to lava extrusion, all conducive to cratonization. Finally Archean (D) crust (cycle 8+) contains the well known low-to-medium grade granitoid-greenstone belts and higher grade gneiss-migmatite terrains, commonly granulitic. Up to three generations of greenstone belts are known in some regions. Numerous accretion-differentiation episodes occurred locally in near-continuous succession. Widespread tonalite plutonism led to rapid growth of stable cratons. In keeping with its antiquity and uniqueness the nature of the formative plate tectonic processes is largely unresolved.

In brief, Atlantic region continental crust evolved in successive stages under the influence of regular, ca. 400 Ma-long tectonic cycles. Data point to a variety of operative tectonic processes ranging from widespread ocean floor consumption (Wilson cycle) to entirely ensialic (Ampferer-style subduction or simple crustal attenuation-compression). Different processes may have operated concurrently in some or different belts. Resolving this remains the major challenge.

Table 1. Areal Proportions by Era of Exposed and Buried Precambrian Crust in Precambrain Platforms, Atlantic Region.

Precambrian Platform ($10^3 km^2$)	Precambrian Era and Eon (%)			
	Proterozoic Era			
	A. Late (0.6-1.0 Ga)	B. Mid- (1.0-1.8 Ga)	C. Early (1.8-2.6 Ga)	D. Archean Eon (+2.6 Ga)
I Exposed Crust Only in Platform				
Europe (1,595)	35	17	28	20
North America (5,969)	10	23	37	30
South America (5,366)	33	36	15	16
Africa (10,684)	54	8	18	20
Total Atlantic Region (23,614)	36	19	23	22
II Combined Crust (exposed + buried) in Platform				
Europe (7,572)	45	11	20	24
North America (19,470)	4	30	49	17
South America (12,969)	48	28	17	7
Africa (28,381)	75	6	7	12
Total Atlantic Region (68,392)	46	18	22	14

Table 2. Relative Sizes by Continent of 1) Precambrian platforms 2) adjoining Phanerozoic mobile belts, and 3) combined continental crust.

Continent	Precambrian Platform		Phanerozoic Mobile Belts		Combined Continental Crust	
	Size ($10^3 Km^2$)	Ratio	Size ($10^3 Km^2$)	Ratio	Size ($10^3 Km^2$)	Ratio
Europe	7,572	1	15,846	1	23,418	1
North America	19,470	2.6	13,122	0.8	32,592	1.4
South America	12,969	1.7	4,152	0.3	17,121	0.7
Africa	28,381	3.7	1,396	0.1	29,777	1.3
Total	68,392	9.0	34,516	2.2	102,908	4.4

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